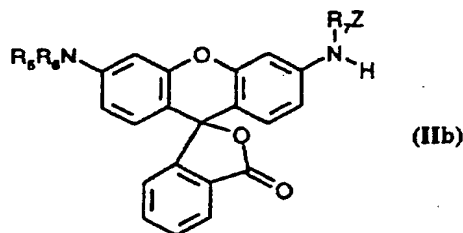
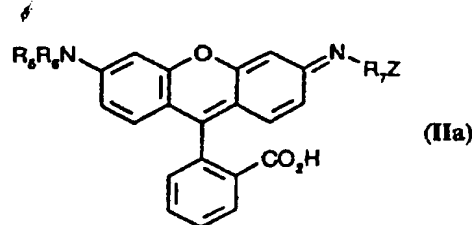
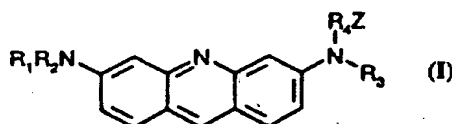




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(71) Applicant (for all designated States except US): CIBA-GEIGY AG [CH/CH]; Klybeckstrasse 141, CH-4002 Basle (CH).		Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
(72) Inventors; and			
(75) Inventors/Applicants (for US only): ALDER, Alex [CH/CH]; Häglerstrasse 22, CH-4422 Arisdorf (CH). BARNARD, Steven, Mark [US/US]; Building 3, Apartment 1, 312 Washington Street, Wellesley Hills, MA 02181 (US). BECK-ELMANN, Dirk [DE/DE]; Heidenkopferdell 67, D-66123 Saarbrücken (DE). BERGER, Joseph [IL/CH]; Sperrstrasse 40/18, CH-4057 Basle (CH). WALDNER, Adrian [CH/CH]; Holceweg 39, CH-4123 Allschwil (CH).			
(74) Common Representative: CIBA-GEIGY AG; Patentabteilung, Klybeckstrasse 141, CH-4002 Basle (CH).			

(54) Title: POLYMER-BOUND FLUOROPHORES AS OPTICAL ION SENSORS



(57) Abstract

The invention relates to compounds of formula (I), (IIa) or (IIb), wherein R₁, R₂, R₅ and R₆ are each independently of one another hydrogen, -SO₂-(C₁-C₆)alkylphenyl, C₁-C₃₀alkyl, C₁-C₃₀alkyl-CO- or a radical of formula -(C_nH_{2n}-O)_m-R₁₀; R₃ is hydrogen or -SO₂-(C₁-C₆)alkylphenyl; R₄ and R₇ are C₁-C₃₀alkylene or a radical of formula -(C_nH_{2n}-O)_m-R₁₀; Z is a functional group which is selected from the group consisting of -OH, -SH, -NH₂, -COOH, -NCO, -CO-NR₈YR₉Y, -NH-CO-CH=CH₂, -NH-CO-C(CH₃)=CH₂; R₈ and R₉ are each independently of the other C₁-C₃₀alkylene; R₁₀ is a direct bond or C₁-C₁₂alkylene; n is a number from 2 to 6, and m is a number from 1 to 10, with the proviso that the total number of carbon atoms is at most 30; and Y is -OH or -SH. The compounds are used as comonomers for the preparation of copolymer membranes for plasticiser-free ion sensors.

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Polymer-bound fluorophores as optical ion sensors

The present invention relates to functionalised rhodamines and acridines, to processes for their preparation as well as to polyacrylates, polymethacrylates and polyurethanes which contain these rhodamines or acridines bound covalently via their functional groups. The invention also relates a) to an optical sensor, comprising the polymer-bound fluorophores, counterions in the form of lipophilic salts and a ionophore, b) to a process for the optical determination of ions by the fluorescence method, e.g. of cations selected from the group consisting of metal cations and ammonium cations, or e.g. of anions selected from the group consisting of anions of inorganic or organic acids, and also c) to the use of the optical sensor for the determination of anions or cations, in particular in aqueous solutions.

In recent times, the optical determination of ions has become more important, the presence or concentration of ions being measured, for example, via the change in absorption or fluorescence of a suitable dye. The sensors, which are also termed optrodes, usually consist of a transparent carrier material and an active layer. Said active layer normally comprises a transparent hydrophobic polymer and a lipophilic plasticiser to achieve sufficient diffusion of the ions and solubility of the active components. Active components are a specific ionophore as sequesterant for ions, a counterion to maintain the electric neutrality and an indicator substance which produces a measurable optical signal resulting from a chemical or physical change of the environment.

US-A-4 645 744 describes such systems wherein the indicator substance is a neutral compound such as a dye (p-nitrophenol) which interacts with a ionophore/metal cation complex resulting in an optically measurable signal in the form of a change in colour. The interaction can, for example, cause the removal of a proton from a dye resulting in a change of the electron state. Fluorescent compounds (e.g. fluorescein) are also cited as suitable, the fluorescence of which can be altered by the change in the electron state and can be optically determined via fluorescence measurements.

In Chemical, Biochemical and Environmental Fiber Sensors II, SPIE Vol. 1368, pages 165 to 174 (1990), H. He et al. describe systems using a proton carrier (nile blue) as indicator substance, in which systems the transport of potassium into the active layer using valinomycin as ionophore dissociates the proton carrier and one proton diffuses into the aqueous phase. The proton carrier changes its colour from blue to red and, depending on the chosen wavelength, it is possible to determine the decrease in fluorescence of the blue

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dye or the corresponding increase in fluorescence of the red dye. Owing to higher sensitivity and selectivity, it is preferred to measure the fluorescence. One substantial disadvantage of the process is the low sensitivity of the system which is due to the low quantum yield of fluorescence of the indicator dye employed.

In Anal. Chem. Vol. 62, pages 1528-1531 and 2054-2055, Y. Kawabata describes a membrane system for the optical determination of potassium which is based on the use of a hydrophobic ion exchanger, namely 3,6-bis(dimethylamino)-10-dodecyl-acridinium bromide or 3,6-bis(dimethylamino)-10-dodecyl-10-hexadecyl-acridinium bromide. A change in fluorescence is achieved by changing the polarity of the microenvironment of the sample because the acridinium salts diffuse via ion exchange with the potassium ion to the interface of the aqueous phase.

The systems commonly known today comprise in the active layer high molecular weight hydrophobic polymers (typically PVC) in combination with a plasticiser to ensure fast response times and sufficient sensitivities. In these membrane materials, long-term stability and repeated use is severely restricted because the plasticiser and other low molecular weight components such as ionophores or fluorophores are washed out in the course of time.

The state of the art tries to solve the long-term stability problem of the optical sensor by introducing highly lipophilic groups into the components employed.

While the use of thick membranes also prolongs the long-term stability of the optical sensor, response time and sensitivity are adversely affected by their use, as is described by Th. Rosatzin in Anal. Chem. 1992, 64, 2029-2035.

So far no plasticiser-free polymeric systems have become known which use an ion exchange mechanism for the optical determination of ions based on the determination of the change in fluorescence of a polymer-bound fluorophore.

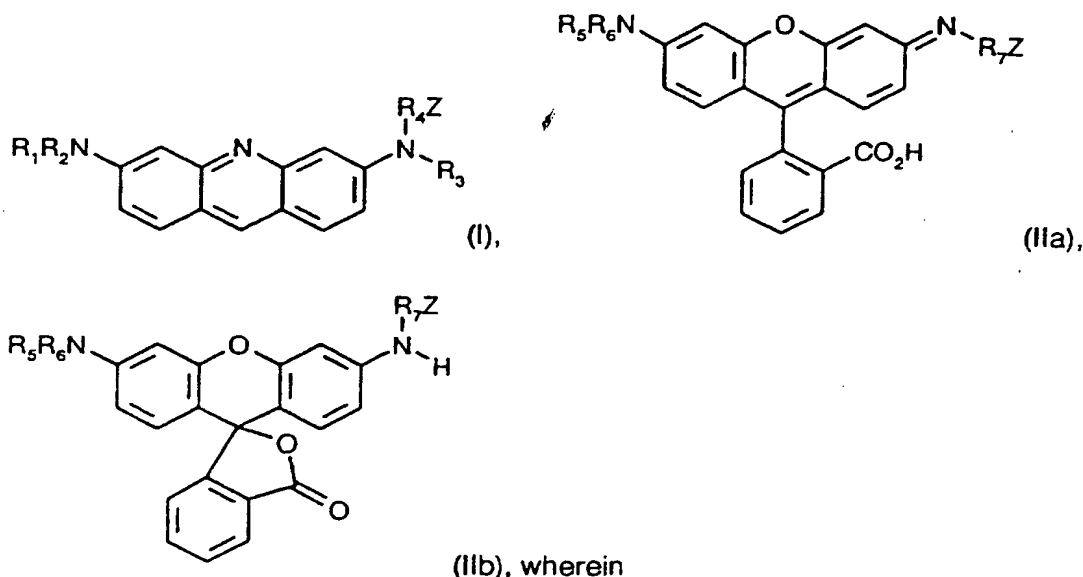
It has now been found that it is possible to prepare specific functionalised acridine and rhodamine dyes and to attach them to polyacrylates or polyurethanes which, surprisingly, meet the high demands made on them regarding sensitivity and response time without adding a plasticiser to the system. The systems have high sensitivity while having short response times. Said polymerically bound acridine and rhodamine dyes are lipophilic, pH-

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sensitive as well as strongly basic fluorophores which are excellently suited for use in a neutral plasticiser-free polymer membrane of low glass transition temperature T_g together with a ionophore and a counterion for determining ions according to the ion exchange mechanism. Their fluorescence depends strongly on the corresponding ion concentrations. The fluorophores are distinguished by a high quantum yield of fluorescence, high basicity, a great difference between the fluorescence signals of the protonated and deprotonated form, high lipophilic properties, sufficient photostability and suitable absorption and emission wavelengths. It is possible to fabricate highly sensitive systems for the optical determination of ions based on fluorescence measurements.

It is possible to substantially increase the working life and frequency because the polymers in the membrane can be plasticiser-free hydrophobic polymers having a defined low glass transition range and because no washing-out of the fluorophores need be feared. This is a special advantage in particular in very thin membranes having fast response times.

In one of its aspects, the invention relates to compounds of formula I, IIa or IIb



R_1 , R_2 , R_5 and R_6 are each independently of one another hydrogen, $-\text{SO}_2-(\text{C}_1-\text{C}_6)\text{alkyl-phenyl}$, $\text{C}_1-\text{C}_{30}\text{alkyl}$, $\text{C}_1-\text{C}_{30}\text{alkyl-CO-}$ or a radical of formula $-(\text{C}_n\text{H}_{2n}-\text{O})_m-\text{R}_{10}$;

R_3 is hydrogen or $-\text{SO}_2-(\text{C}_1-\text{C}_6)\text{alkylphenyl}$;

R_4 and R_7 are $\text{C}_1-\text{C}_{30}\text{alkylene}$ or a radical of formula $-(\text{C}_n\text{H}_{2n}-\text{O})_m-\text{R}_{10}$;

Z is a functional group which is selected from the group consisting of $-\text{OH}$, $-\text{SH}$, $-\text{NH}_2$, $-\text{COOH}$, $-\text{NCO}$, $-\text{CO-NR}_8\text{YR}_9\text{Y}$, $-\text{NH-CO-CH=CH}_2$, $-\text{NH-CO-C}(\text{CH}_3)=\text{CH}_2$;

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R_8 and R_9 are each independently of the other C_1 - C_{30} alkylene;

R_{10} is a direct bond or C_1 - C_{12} alkylene;

n is a number from 2 to 6, and m is a number from 1 to 10, with the proviso that the total number of carbon atoms is at most 30;

and Y is $-OH$ or $-SH$.

The alkyl groups can be linear or branched and preferably contain 1 to 24 carbon atoms. Linear alkyl groups are preferred. Typical examples of alkyl are methyl, ethyl and the positional isomers of propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, hexadecyl, heptadecyl, octadecyl, nonadecyl, eicosyl, heneicosyl, docosyl, tricosyl, tetracosyl, and tricontyl.

$-SO_2-(C_1-C_6)Alkylphenyl$ is preferably toluenesulfonyl.

C_2 - C_{30} Alkylene can be linear or branched and preferably contains 2 to 20, particularly preferably 2 to 16, carbon atoms. Linear alkylene is preferred. Typical examples are methylene, ethylene and the positional isomers of propylene, butylene, pentylene, hexylene, heptylene, octylene, nonylene, decylene, undecylene, dodecylene, tridecylene, tetradecylene, pentadecylene, hexadecylene, heptadecylene, octadecylene, nonadecylene, eicosylene, heneicosylene, docosylene, tricosylene, tetracosylene, and tricontylene.

In the radical of formula $-(C_nH_{2n}-O)_m-R_{10}$, n is preferably 2 to 4, m is preferably 2 to 6, and R_{10} is preferably either a direct bond or C_2 - C_4 alkylene.

Illustrative examples of C_2 - C_{30} alkylene bridge groups which are interrupted by oxygen atoms are those which are derived from ethylene oxide, propylene oxide, butylene oxide or isobutylene oxide.

R_1 and R_2 in the compounds of formula I are preferably each independently of the other hydrogen or linear C_{12} - C_{24} alkyl, the carbon atom number of R_1 and R_2 together preferably being from 10 to 20.

R_4 is preferably linear C_2 - C_{16} alkylene or a radical of formula $-(C_2H_4-O)_m-R_{10}$, wherein R_{10} and m have the meanings cited above.

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R_5 and R_6 in the compounds of formula II, IIa or IIb are preferably each independently of the other linear C_2 - C_{12} alkyl. R_5 and R_6 are particularly preferably identical and are linear C_2 - C_6 alkyl.

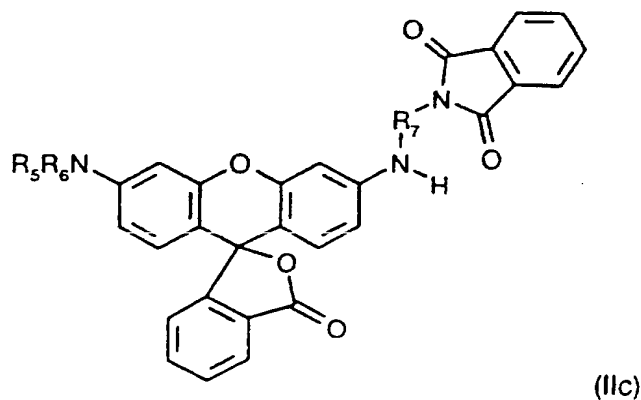
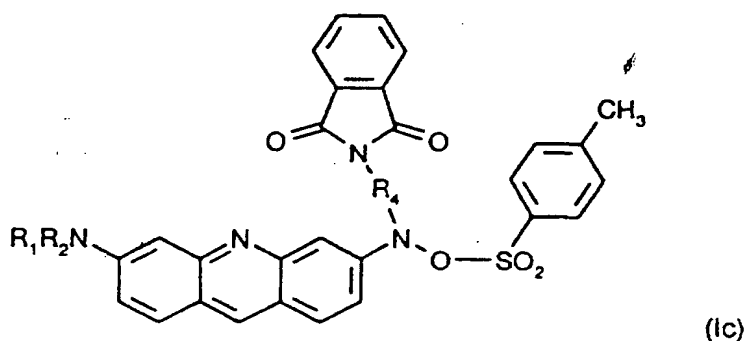
R_7 in the compounds of formula IIa or IIb is preferably linear C_2 - C_{16} alkylene.

Preferred compounds are those of formula I, IIa or IIb, wherein the functional group Z is -OH, -NH₂, -CO-NR₈YR₉Y or -NH-CO-CCH₃=CH₂, and R_8 and R_9 are each independently of the other C_2 - C_8 alkylene. Y is preferably OH.

The compounds of formulae I, IIa and IIb preferably have a pK_a value of at least 8, particularly preferably of at least 10. The pK_a value can be adjusted by the choice and combination of R_1 to R_7 .

In another of its aspects, the invention relates to a process for the preparation of the compounds of formulae I, IIa and IIb, which comprises

a) removing the phthalimide group in the compounds of formula Ic or IIc



under acid conditions and, where appropriate,

b) reacting the reaction products further with acrylic acid chloride or methacrylic acid chloride in a second step or,

c) where appropriate, removing the p-toluenesulfonyl group in the reaction products of the educts of formula Ic under acid conditions,

R₁, R₂, R₄, R₅, R₆ and R₇ having the meanings cited above.

The processes for removing the protective groups are known per se and can be used in analogous manner for the preparation of the compounds of formulae I, IIa and IIb.

The compounds of formula Ic can be prepared in a manner known per se by stepwise alkylation using different alkylating agents or by alkylation using an alkylating agent or acylating agent of the commercially available 3,6-diaminoacridine. Suitable alkylating agents are, for example, dialkyl sulfates or monohalogen alkanes, preferably chloroalkanes, bromoalkanes and iodoalkanes. Suitable acylating agents are, for example, carboxylic acid anhydrides and, preferably, carboxylic acid halides, typically carboxylic acid chlorides. This reaction can be carried out in the presence of inert polar and aprotic solvents, typically ethers, alkylated acid amides and lactames or sulfones, and at elevated temperatures, e.g. from 50 to 150°C. It is expedient to add a hydrogen halide scavenger, typically alkali metal carbonates or tertiary amines and, preferably, sterically hindered tertiary amines.

In one possible method of preparing the compounds of formula I, the starting compound is 3,6-diaminoacridine which is reacted in a first step with p-toluenesulfonic acid chloride. The purified reaction product is reacted first e.g. with a compound R₂-Br at one nitrogen atom and e.g. with Br-R₄-phthalimide at a second nitrogen atom. Further reaction with e.g. hydrazine hydrate gives a compound of formula I.

The compounds of formula IIc are typically obtainable by reacting phthalic acid anhydride with 2 molar equivalents of 3-monoalkylaminophenol. Another possible method of preparation consists in reacting 3-monoalkylaminophenol with 1 molar equivalent of 2-hydroxy-4-dialkylamino-2'-carboxylbenzophenone. These reactions are described, inter alia, in US-A-4 622 400. The reaction is conveniently carried out in an inert solvent, typically hydrocarbons or ethers. Molar amounts of a condensing agent are usefully added, typically Lewis acids, concentrated sulfuric acid, perchloric acid or phosphoric acid. The reaction temperature is typically in the range from 50 to 250°C.

The compounds of formula I, IIa and IIb can be isolated in conventional manner by precipitation, crystallisation or extraction and, where required, can be purified by recrystallisation or by chromatographic methods. Said compounds are crystalline and dy d e.g. a red, reddish brown or reddish violet colour.

The p-toluenesulfonyl group can be removed by known methods, such as described in J. Chem. Soc. Chem. Com. 1973, 664.

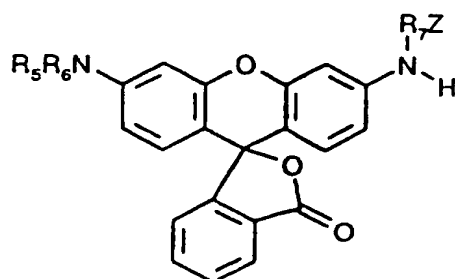
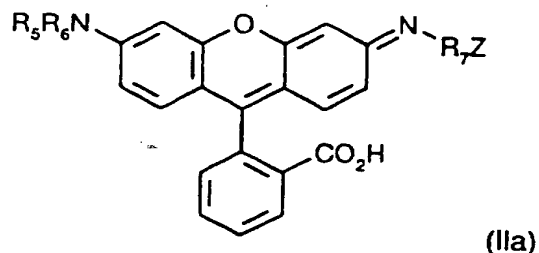
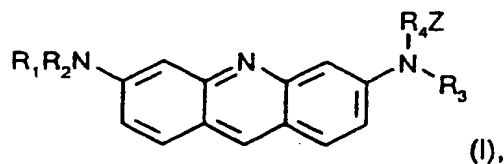
A process for the preparation of the compounds of formula IIa or IIb can typically be carried out such that 4-(2'-carboxy)benzoyl-3-hydroxy-N,N-diethylaniline is first placed in a reaction vessel and reacted with 3-methoxy-N-(3-aminopropyl)aniline. The resulting reaction product is a compound of formula IIa or IIb. This compound can be further reacted by known methods, typically with methacryloyl chloride, again resulting in a compound of formula IIa or IIb.

The compounds of formula I, IIa or IIb are excellently suited for covalent attachment at polymers selected from the group consisting of polyurethanes, polyureas and polyurea-polyurethanes.

The compounds of formula I, IIa or IIb are also excellently suited for the preparation of copolymers from olefinically unsaturated monomers, in which case Z is $-NH-CO-CH=CH_2$ or $-NH-CO-C(CH_3)=CH_2$. Some illustrative examples of olefinically unsaturated monomers are acrylic acid, methacrylic acid, maleic acid, maleic acid anhydride, C_1-C_{30} acrylic acid ester and C_1-C_{30} methacrylic acid ester, C_1-C_{30} acrylic acid amide and C_1-C_{30} methacrylic acid amide, or acrylic acid amide and methacrylic acid amide, vinyl ester of C_1-C_{20} carboxylic acids, acrylonitrile, butadiene, isoprene, chlorobutadiene, styrene, α -methylstyrene, vinyl chloride, vinyl fluoride, vinylidene chloride and vinyl ether of C_1-C_{30} alcohols.

The invention also relates to a copolymer which is plasticiser-free and which consists either
A) of at least one diol or at least one diamine or of mixtures of at least two of these monomers, and of at least one diisocyanate, or
B) of at least one olefinically unsaturated monomer, which copolymer additionally contains at least one comonomer of formula I, IIa or IIb

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Z is -OH, -SH, -NH₂, -COOH, -NCO, or NR₈YR₉Y and Y is -OH or -SH and, in the case of B) Z is -NH-CO-CH=CH₂ or -NH-CO-CCH₃=CH₂, and R₁, R₂, R₃, R₄, R₅, R₆, R₇, R₈ and R₉ have the meanings and preferred meanings cited above.

The copolymer is preferably formed by at least one diol or diamine and one diisocyanate.

The compounds of I, IIa or IIb are preferably present in an amount of 0.01 to 10 % by weight, more preferably of 0.1 to 5 % by weight and, most preferably, of 0.1 to 2 % by weight, based on the amount of polymer.

Copolymer A) can be polyurethane, polyurea or polyureapolyurethane.

Polymer A) is preferably a polyurethane consisting of polyethers of C₃-C₆alkanediols, polyoxyalkylenediols or hydroxy-terminated siloxanes and aliphatic, cycloaliphatic, cycloaliphatic-aliphatic, aromatic-aliphatic or aromatic C₂-C₂₀diisocyanates.

Preferred diisocyanates are those selected from the group consisting of 1,6-bis[isocyanate]-hexane, 5-isocyanate-3-(isocyanatemethyl)-1,1,3-trimethylcyclohexane, 1,3-bis[5-isocyanate-1,3,3-trimethylphenyl]-2,4-dioxo-1,3-diazetidene, 3,6-bis[9-isocyanatenonyl]-4,5-di(1-heptenyl)cyclohexene, bis[4-isocyanatecyclohexyl]methane, trans-1,4-bis[isocyanate]-cyclohexane, 1,3-bis[isocyanatemethyl]benzene, 1,3-bis[1-isocyanate-1-methylethyl]-benzene, 1,4-bis[2-isocyanate-ethyl]cyclohexane, 1,3-bis[isocyanatemethyl]cyclohexane, 1,4-bis[1-isocyanate-1-methylethyl]benzene, bis[isocyanate]isododecylbenzene, 1,4-

bis[isocyanate]benzene, 2,4-bis[isocyanate]toluene, 2,6-bis[isocyanate]toluene, 2,4-/2,6-bis[isocyanate]toluene, 2-ethyl-1,2,3-tris[3-isocyanate-4-methylanilinoxy]propane, N,N'-bis[3-isocyanate-4-methylphenyl]urea, 1,4-bis[3-isocyanate-4-methylphenyl]-2,4-dioxo-1,3-diazetidine, 1,3,5-tris[3-isocyanate-4-methylphenyl]-2,4,6-trioxohexahydro-1,3,5-triazine, 1,3-bis[3-isocyanate-4-methylphenyl]-2,4,5-trioximidazolidine, bis[2-isocyanatephenyl]-methane, (2-isocyanatephenyl)-(4-isocyanatephenyl)methane, bis[4-isocyanatephenyl]-methane, 2,4-bis[4-isocyanatebenzyl]-1-isocyanatebenzene, [4-isocyanate-3-(4-isocyanatebenzyl)phenyl]-[2-isocyanate-5-(4-isocyanatebenzyl)phenyl]methane, tris[4-isocyanatephenyl]methane, 1,5-bis[isocyanate]naphthalene, or 4,4'-bis[isocyanate]-3,3'-dimethylbiphenyl.

Particularly preferred diisocyanates are those selected from the group consisting of 1,6-bis[isocyanate]hexane, 5-isocyanate-3-(isocyanatemethyl)-1,1,3-trimethylcyclohexane, 2,4-bis[isocyanate]toluene, 2,6-bis[isocyanate]toluene, 2,4-/2,6-bis[isocyanate]toluene, bis[4-isocyanatecyclohexyl]methane or bis[4-isocyanatephenyl]methane.

Particularly suitable polyurethanes are obtained by reacting

- a) 5-45 % by weight of an aromatic, cycloaliphatic or linear aliphatic diisocyanate,
- b) 0-20 % by weight of a linear or branched C₂-C₁₂alkylenediol
- c) 0-75 % by weight of a polytetrahydrofuran
- d) 0-10 % by weight of a polyethylene glycol
- e) 0-75 % by weight of a polypropylene glycol and
- f) 15-95 % by weight of a hydroxy-terminated or hydroxypropyl-terminated polydimethylsiloxane
- g) 0.1-5 % by weight of a fluorophore of formula I, IIa or IIb,

where the percentages are based on the amount of polymer and the parts by weight of the components a) to g) give a sum of 100. A thermoplastic, randomly segmented polyurethane is obtained.

The hydroxy-terminated or hydroxypropyl-terminated polydimethylsiloxane preferably has a molecular weight of 900 to 4500 dalton.

The polytetrahydrofuran preferably has a molecular weight of 1000 to 4500 dalton.

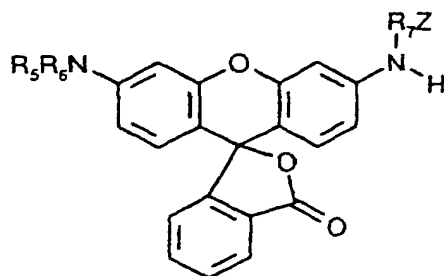
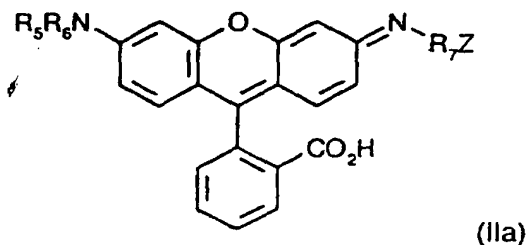
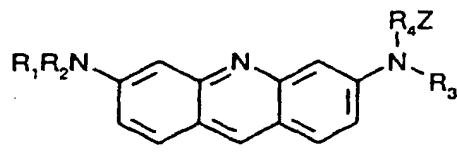
Polyethylene glycol preferably has a molecular weight of 600 to 2000 dalton, and polypropylene glycol preferably has a molecular weight of 1000 to 4000 dalton.

The preparation of the polyurethanes can be carried out according to processes which are known per se.

The compounds of formula I, IIa or IIb can either be added from the start to the reaction mixture for the preparation of polyurethane. However, it is also possible to react the compounds of formula I, IIa or IIb first with excess diisocyanate and then to mix the reaction product with the diol or polyol components. Another possibility consists in diluting the diol or polyol component with a hyperstoichiometric amount of diisocyanate and subsequently reacting the compounds of formula I with the excess diisocyanate.

The polymers obtained have essentially terminally bound fluorophors.

Another group of preferred copolymers is obtained by selecting the monomers from the compounds of the group consisting of acrylic acid, methacrylic acid, maleic acid, maleic acid anhydride, C₁-C₃₀acrylic acid ester and C₁-C₃₀methacrylic acid ester, C₁-C₃₀acrylic acid amide and C₁-C₃₀methacrylic acid amide or acrylic acid amide and methacrylic acid amide, vinyl ester of C₁-C₂₀carboxylic acids, acrylonitrile, butadiene, isoprene, styrene, α -methylstyrene, and vinyl ether of C₁-C₃₀alcohols and a compound of formula I, IIa or IIb



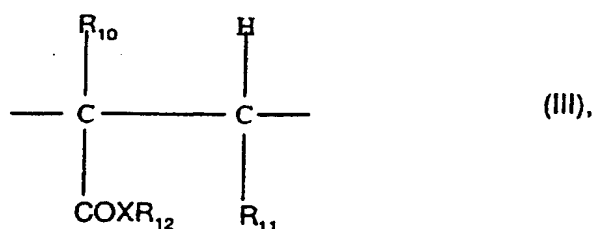
have the meanings and preferred meanings cited above and Z is -NH-CO-CH=CH₂ or -NH-CO-C(CH₃)=CH₂.

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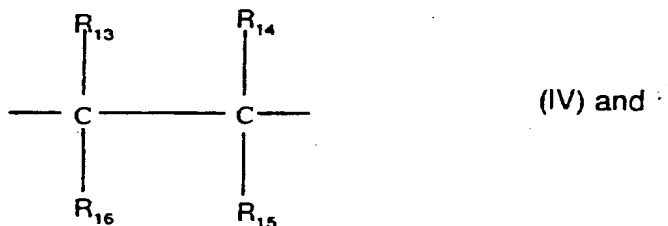
The compounds of formula I, IIa or IIb are preferably present in an amount of 0.01 to 10 % by weight, preferably of 0.1 to 5 % by weight and, very particularly preferably, of 0.1 to 2 % by weight, based on the entire polymer.

In another preferred embodiment of this invention, the copolymers comprise

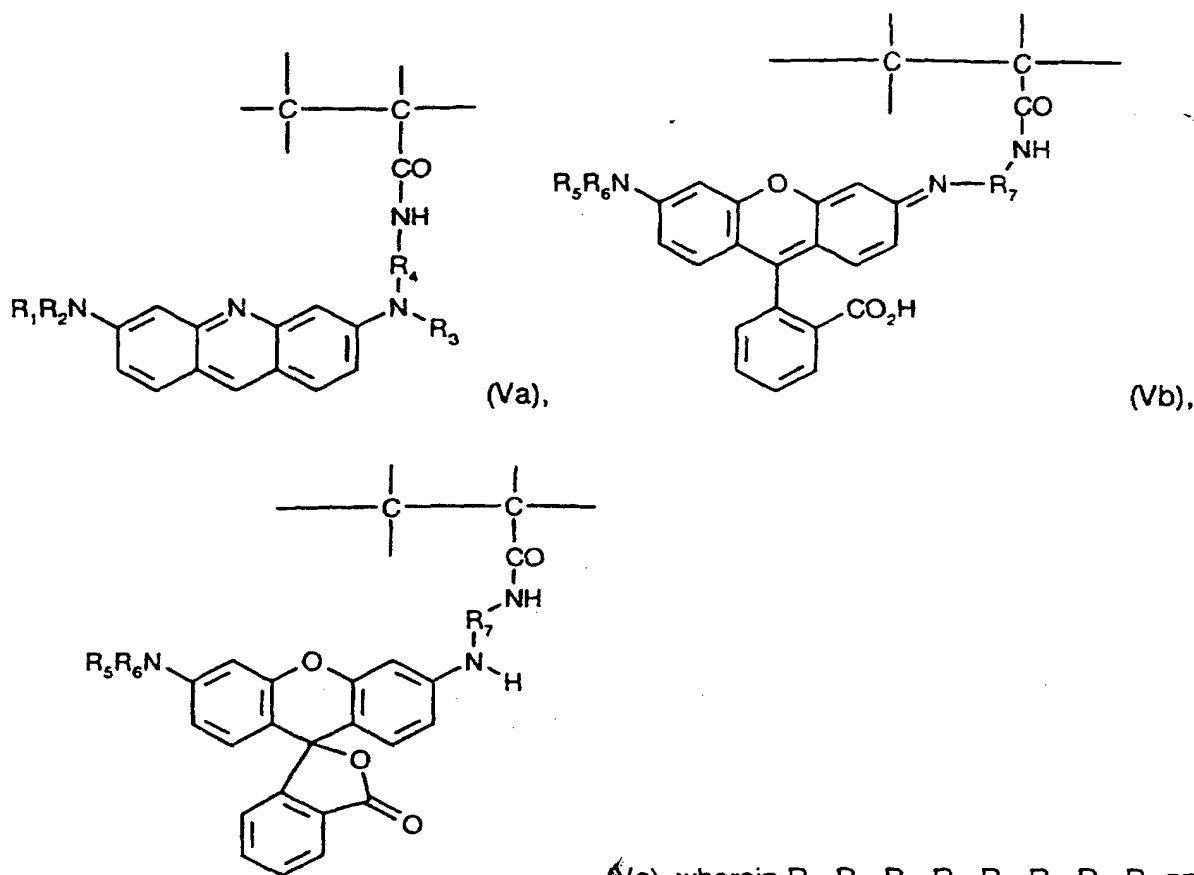
a) 10 to 90 % by weight, preferably 20 to 80 % by weight and, particularly preferably, 30 to 70 % by weight, based on the polymer, of identical or different structural elements of formula III



b) 90 to 10 % by weight, preferably 80 to 20 % by weight and, particularly preferably, 70 to 30 % by weight, based on the polymer, of identical or different structural elements of formula IV



c) 0.1 to 5 % by weight of at least one compound of formula Va, Vb or Vc



(Vc), wherein R_1 , R_2 , R_3 , R_4 , R_5 , R_6 , R_7 , R_8 and

R_9 have the meanings and preferred meaning cited above;

R_{10} and R_{11} are each independently of the other H or C_1 - C_4 alkyl, X is -O- or $-NR_{17}$, R_{12} is C_1 - C_{20} alkyl and R_{17} is H or C_1 - C_{20} alkyl;

R_{13} and R_{14} are each independently of the other H, F, Cl or C_1 - C_4 alkyl, R_{15} and R_{16} are each independently of the other H, F, Cl, C_1 - C_4 alkyl, $-COOH$, $-COO-C_1-C_5$ alkyl, $-CONHC_1-C_5$ alkyl or $-CON(R_{17})C_1-C_5$ alkyl, or R_{15} is H and R_{16} is $-CN$, phenyl, chlorophenyl, C_1 - C_{12} alkoxy or C_2 - C_{18} acyloxy.

R_{10} is preferably H or methyl and R_{11} is preferably H. X is preferably -O-. R_{12} is preferably C_1 - C_{16} alkyl. Illustrative examples of R_{12} are methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, 2-ethylhexyl, nonyl, decyl, dodecyl, tetradecyl and hexadecyl.

R_{13} is preferably H or methyl, R_{14} is preferably H, and R_{15} is preferably H. R_{16} is preferably $-CN$, phenyl, $-COO-C_1-C_4$ alkyl, C_1 - C_4 alkoxy or C_2 - C_6 acyloxy. Typical examples of acyloxy are acetyloxy, propionyloxy, butyroyloxy, pentanoyloxy and hexanoyloxy.

A particularly preferred copolymer is that wherein the monomers forming the polymer are selected from the group consisting of C_1 - C_{16} acrylic acid alkyl esters, C_1 - C_{16} methacrylic acid alkyl esters, acrylamide, methacrylamide and the corresponding N-substituted derivatives, or acrylonitrile.

The preparation of these polymers can be carried out according to known polymerisation processes and the compounds of formula I, IIa or IIb can be added e.g. at the beginning or at a later time.

Depending on the process of preparation and the time of addition, the resulting fluorophores are essentially terminally or randomly distributed in the polymers.

It is also possible to use alkyleneetriols in minor amounts, typically 1,1,1-tris(hydroxymethyl)-ethane in an amount of 0.1 to 5 % by weight, based on the polymer. Under these conditions, no detectable crosslinking takes place yet and the resultant polyurethane remains soluble in organic solvents.

Where the copolymer is formed from olefinically unsaturated monomers, diolefinic monomers can also be added in minor amounts as crosslinkers.

The polymer preferably has a glass transition temperature in the range from -150°C to 50°C , particularly preferably from -125°C to -40°C .

The molecular weight of the polymer is preferably from 10 000 to 250 000 dalton, more preferably from 10 000 to 100 000 dalton and, most preferably, from 10 000 to 30 000 dalton.

The dielectric constant of the polymer at 100 Hz and at room temperature is preferably from 2 to 25, particularly preferably from 5 to 15. The optical transparence is preferably in the range from 400 to 1200 nm, particularly preferably from 400 to 900 nm.

The invention also relates to an optical sensor consisting of
(a) a transparent carrier which is coated on at least one side with a transparent layer of a plasticiser-free polymer of this invention,

- (b) counterions in the form of lipophilic salts, and
- (c) a ionophore which forms a complex with the ion to be determined.

The carrier can, for example, be constructed from a plastic material, typically polycarbonate or acrylic glass, mineral materials or glass and may be in any form, e.g. plates, cylinders, tubes, ribbons or filaments. Glasses are preferred.

The layer thickness on the carrier can be, for example, from 0.01 to 100 μm , preferably from 0.1 to 50 μm , more preferably from 0.1 to 30 μm and, particularly preferably, from 0.1 to 10 μm .

Preferred salts containing lipophilic anions are alkali metal salts and ammonium salts with unsubstituted or substituted tetraphenylborates.

Particularly preferred cations are Li^+ , Na^+ , K^+ , NH_4^+ , and the ammonium cations of primary, secondary and tertiary amines as well as quaternary ammonium cations containing 1 to 60 carbon atoms.

Illustrative examples of ammonium cations are methyl ammonium, ethyl ammonium, propyl ammonium, butyl ammonium, hexyl ammonium, octyl ammonium, decyl ammonium, dodecyl ammonium, tetradecyl ammonium, hexadecyl ammonium, octadecyl ammonium, dimethyl ammonium, diethyl ammonium, dibutyl ammonium, butylmethyl ammonium, dioctyl ammonium, didoetyl ammonium, dodecylmethyl ammonium, trimethyl ammonium, triethyl ammonium, tripropyl ammonium, tributyl ammonium, trioctyl ammonium, tridodecyl ammonium, dodecyltrimethyl ammonium, didodecylmethyl ammonium, tetramethyl ammonium, tetraethyl ammonium, tetrapropyl ammonium, tetrabutyl ammonium, tetrahexyl ammonium, tetraoctyl ammonium, tetradecyl ammonium, tetradodecyl ammonium, dodecyltrimethyl ammonium, octyltrimethyl ammonium, didodecyltrimethyl ammonium, tridodecylmethyl ammonium, tetradecyltrimethyl ammonium and octadecyltrimethyl ammonium. Quaternary ammonium salts are preferred, in particular those containing 4 to 48 carbon atoms.

Borate anion is preferably unsubstituted tetraphenylborate or tetraphenylborate which is substituted at the phenyl groups by one or more than one $\text{C}_1\text{-C}_4$ alkyl, $\text{C}_1\text{-C}_4$ alkoxy, halogen, typically F, Cl, Br or I, or trifluoromethyl.

Particularly preferred are sodium tetraphenylborate, sodium tetra(3,5-bistrifluoromethylphenyl)borate, potassium tetra(4-chlorophenyl)borate, tetrabutyl ammonium tetraphenyl-

- 15 -

borate and tetradodecyl ammonium(4-chlorophenyl)borate. The salts containing lipophilic anions serve as negative charge exchange for cations to be determined which have diffused into the active layer and which are complexed there.

The salts containing lipophilic anions can also be salts of polymers containing acid or basic groups, typically polysulfonic acids or polycarboxylic acids.

The amount of salts containing lipophilic anions is preferably from 0.01 to 10 % by weight, particularly preferably from 0.1 to 5 % by weight, based on the amount of polymer.

Ionophores are organic, natural or synthetic compounds which contain several, mostly alternating, electron-rich hetero atoms, typically S, N and, preferably, O, in an open-chain or cyclic carbon chain and which are capable of selectively complexing the ions to be determined. The natural compounds are often macrocyclic compounds such as valinomycin which is capable of selectively binding potassium cations. Another example is nonactin. A large group of ionophores consists of the macrocyclic polyethers (crown ethers) which, depending on geometry and size, are capable of complexing different metal cations. Other examples of ionophores to be mentioned are coronandenes, cryptandenes and calixarenes. A typical example of open-chain ionophores are the podandenes. Such ionophores are described, inter alia, in US-A-4 645 744.

The nonionic ionophore preferably contains an open-chain carbon chain with several oxygen atoms. Particularly preferred are (R,R)-N,N'-bis[11-ethoxycarbonylundecyl]-N,N',4,5-tetramethyl-3,6-dioxaoctanediamide, N,N-dicyclohexyl-N',N'-dioctadecyl-3-oxapentane-diamide or N,N,N',N'-tetracyclohexyl-3-oxapentane diamide.

The polymer contains the ionophore preferably in an amount of 0.01 to 10 % by weight, particularly preferably in an amount of 0.1 to 5 % by weight, based on the amount of polymer.

The optical sensor preferably contains valinomycin as potassium ionophore.

The preparation of such membranes can be carried out in a manner known per se, typically by dissolving the composition in an organic solvent and then casting it to a film with subsequent removal of the solvent. Once the solvent is removed, the film can be stripped from the base, resulting in a self-supporting membrane.

Further possible processes for the preparation of the membrane are those known from coating technology, typically spinning, spraying or doctor coating processes.

Spin-coating processes are preferred.

Suitable solvents are ethers, esters, acid amides and ketones. Readily volatile solvents are particularly suitable, preferably tetrahydrofuran.

In addition to these processes, which comprise first dissolving the composition, moulding it and then removing the solvent by evaporation, heat moulding processes are also possible because the composition is a thermoplastic material. Suitable heat moulding processes are extrusion, injection moulding, compression moulding or blow moulding processes such as those known from thermoplastic processing.

The membrane can be transparent or slightly opaque. The membrane is preferably transparent.

The fluorophores to be used according to this invention have very suitable ranges of absorption and emission wavelengths which permit the use of known and inexpensive light sources, for example halogen or xenone lamps or light-emitting diodes. Detectors suitable for use are e.g. photodiodes. In addition, the fluorophores have high extinction coefficients and can afford high quantum yields. The high lipophilic properties, high basicity and the great dynamic range of the change between the fluorescence of the protonated and deprotonated form meet in particular the high demands made on an optical determination of ions based on the measurement of the fluorescence. Cations as well as anions can be determined.

Suitable cations are, for example, cations of the metals of the first to fifth main group of the periodic system of the elements, the lanthanides and actinides. Typical examples of metals are Li, Na, K, Rb, Cs, Mg, Ca, Sr, Ba, B, Al, Ga, In, Tl, Sn, Pb, Sb, Bi, Cu, Ag, Au, Zn, Cd, Hg, Sc, Y, Ti, Zr, Hf, Cr, Mo, W, Mn, Fe, Co, Ni, Ru, Os, Rh, Ir, Pt, Pd, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, Lu, Ac, Th, Pa, U, Np, Pu. Preferred cations are the alkali metal cations and alkaline earth metal cations, in particular Li^+ , Na^+ , K^+ , Mg^{2+} , Ca^{2+} and Sr^{2+} , and, more preferably, K^+ , Na^+ and Ca^{++} . Suitable ammonium cations are e.g. NH_4^+ as well as the cations of protonated primary, secondary and tertiary amines and also quaternary ammonium. The amines can contain 1 to 40, preferably 1 to 20 and, more preferably, 1 to

12, carbon atoms. The quaternary ammonium can contain 4 to 40, preferably 4 to 20 and, more preferably, 4 to 16, carbon atoms.

The anions to be determined can be derived from mineralic acids, oxygen acids and inorganic complex acids. Illustrative examples are the halides and pseudohalides F^- , Cl^- , Br^- , I^- , N_3^- , CN^- , OCN^- and SCN^- ; anions of the inorganic oxygen acids NO_2^- , NO_3^- , CO_3^{2-} , PO_4^{3-} , SO_4^{2-} , ClO_4^- , MnO_4^- and ClO_3^- ; anions of the inorganic complex acids $Fe(CN)_6^{4-}$ and $Co(CN)_6^{3-}$; the anions of carboxylic acids, phenols; nucleotide anions such as adenosine phosphate.

The optical sensor is particularly suitable for the quantitative determination of ions, in particular of cations, very particularly of metal cations, typically potassium cations, in aqueous environment, preferably using fluorescence spectrometry. The determinations can be carried out in short time at high accuracy even at low concentrations (e.g. in the μ -molar range up to the nanomolar range) because the pH-dependent equilibria of the complexing reactions and of the proton exchange adjust quickly and because the fluorophores are distinguished by high fluorescence quantum yields and sensitivity. The analyses can be typically carried out direct in body fluids (blood, urine, serum), natural waters or waste waters, while possibly interfering cations can be specifically bound or removed beforehand. The novel composition is particularly suitable for the determination of physiological amounts of cations in aqueous media which, in the case of potassium, may be e.g. in the range from about 0.5 to 10 mmol.

In addition to the preferred fluorescence spectroscopy, other optical methods of measurement can also be used, typically surface plasmon resonance spectroscopy, absorption spectroscopy, reflection spectroscopy, interferometry or surface-enhanced Raman or fluorescence spectroscopy.

The invention also relates to a process for the optical determination of ions in aqueous test samples by contacting a sensor of this invention with said aqueous test sample and then measuring the change in fluorescence of the fluorophore in the polymer layer.

The process of this invention can typically be carried out such that the carrier is mounted with the active polymer layer in an optical cell wherein the active layer is contacted with the test sample. The optical cell contains a window through which the active layer can be

irradiated to excitation and the emitted fluorescent radiation can be measured with a spectrofluorometer. The wavelengths are adjusted such that maximum absorption is obtained for the irradiation and maximum emission is obtained for the fluorescence measurement. The intensity is measured as a function of time. The measuring system can be such that measurement is carried out discontinuously or continuously e.g. by pumping the measuring solution through the measuring cell. To determine unknown concentrations of cations, the system can first be calibrated using test samples of known concentration by applying the concentrations as function of the intensity of the fluorescence. pH buffers are expediently added to the test sample because, owing to the pH dependence of the absorption spectrum of the fluorophore and consequently also of the fluorescence intensity of the fluorophore, the sensitivity of the measurement depends on the pH of the measuring solution. However, in another embodiment of this invention said pH dependence can also be determined and be taken into account in the calculations. The pH range of the test sample can be, for example, 4 to 8, preferably 6.5 to 7.5. Suitable buffers are typically citrate buffers and phosphate buffers. Further buffer systems are described in US-A-4 645 744, in particular also such buffers which are incorporated direct into the active layer to avoid the addition to the test sample.

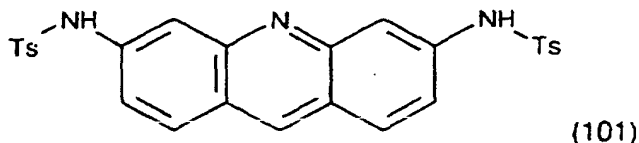
The invention also relates to the use of the optical sensor for the fluorescence spectroscopic analysis of cations or anions.

The following Examples illustrate the invention.

A) Preparation of the intermediate compounds

Ts in the structural formulae hereinbelow denotes a tosyl radical.

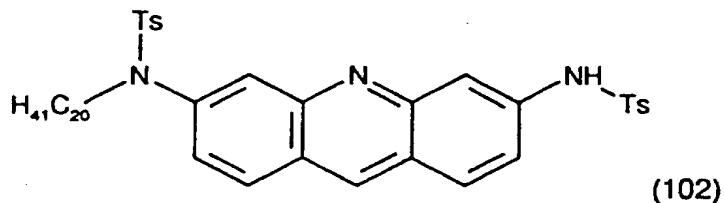
Example A1: Preparation of compound 101



1.21 g of 3,6-diaminoacridine and 2.48 g of 1,8-bisdimethylaminonaphthalene are dissolved in 50 ml of 1,3-dimethyl-2-imidazolinon and then 2.2 g of toluenesulfonyl chloride are added. This mixture is heated to 80°C for 64 hours. The mixture is then poured in water and exhausted with ethyl acetate. The organic phase is dried and concentrated by

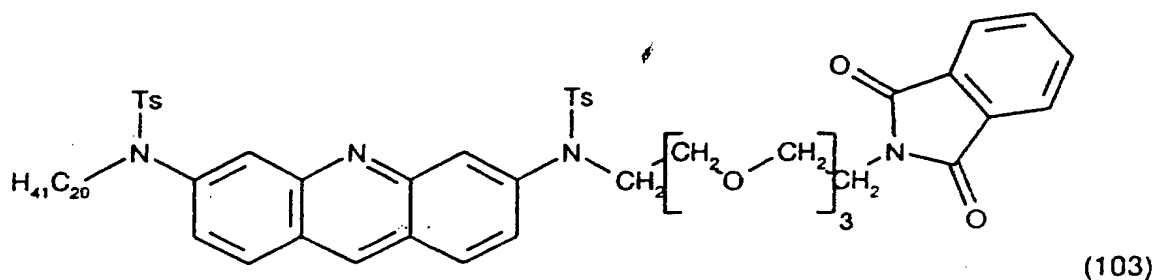
evaporation. The product is purified by column chromatography over silica gel. Yield: 17% red crystals.

Example A2: Preparation of compound 102

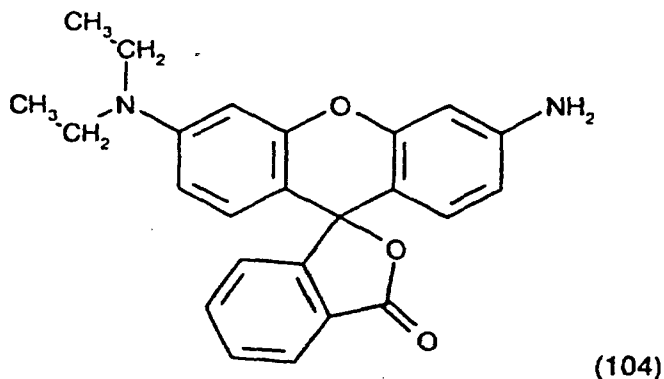


3.0 g of the compound 101 of Example A1 are dissolved together with 5.2 g of 1-bromo-eicosane and 1.0 g of ground KOH in 45 ml of DMF and heated to 40°C for 7 hours. The reaction mixture is poured in 500 ml of water and extracted with ethyl acetate. The organic phase is separated, dried and concentrated by evaporation. The residue is chromatographed over silica gel. Yield: 52% red resin.

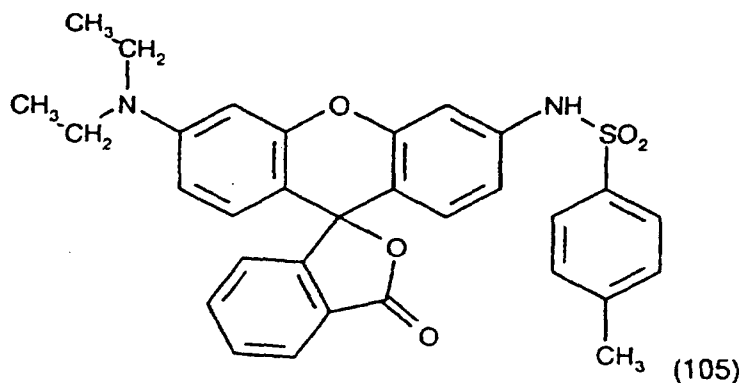
Example A3: Preparation of compound 103



2.4 g of the compound 102 of Example A2, 2.3 g of ω -N-phthalimidoethyltriethoxyethyl bromide and 1 g of potassium carbonate in 30 ml of DMF are heated to 70°C for 20 hours. An additional 0.5 molar equivalent each of bromide and base are then added and the mixture is heated to 70°C for a further 7 hours. The reaction mixture is poured in 300 ml of 2N HCl and extracted with ethyl acetate. The organic phase is separated, dried, concentrated by evaporation and then purified over silica gel. Yield: 60%. MS(FAB): 1102.

Example A4: Preparation of compound 104

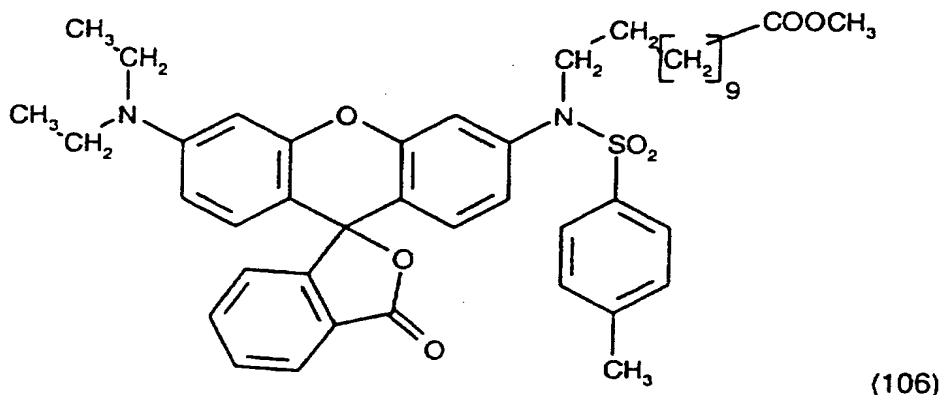
60 ml of sulfuric acid (97%) are placed in a vessel and then 9.4 g (30 mmol) of 4-(2'-carboxy)-benzoyl-3-hydroxy-N,N-diethylaniline are added in increments. 3.6 g (33 mmol) of 3-aminophenol are then added at room temperature and the mixture is stirred for 22 hours at room temperature. The reaction mixture is charged to a mixture of 275 ml of water, 255 ml of 30% NaOH and 200 ml of toluene and stirred for 30 min at 70°C. After cooling to 60°C, the organic phase is separated, dried and concentrated by evaporation. The crude product is purified by chromatography. M.p.: 148-153°C.

Example A5: Preparation of compound 105

500 mg of the compound 104 of Example A4 are dissolved in 20 ml of pyridine and the mixture is cooled to -38°C. To this mixture are then added 492 mg (2 molar equiv.) of p-toluenesulfonyl chloride and the solution is stirred for 1 hour at this temperature. Subsequently, the solution is poured in 1N of HCl and extracted with methylene chloride.

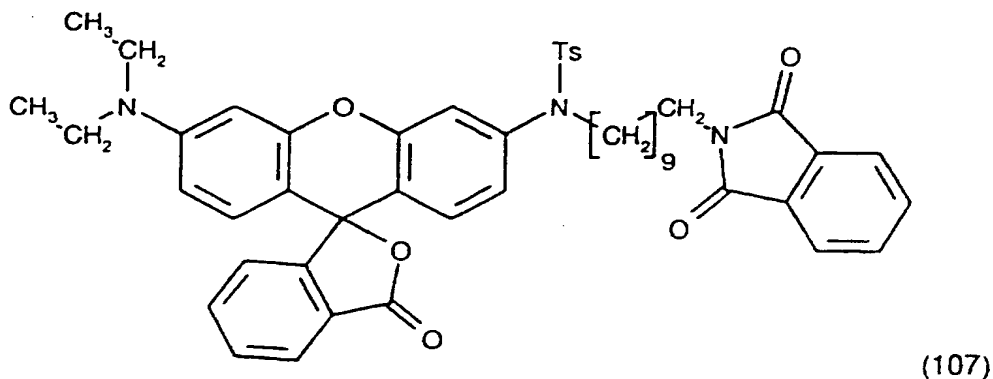
The organic phase is dried and then purified by chromatography. Yield: 60%. M.p.: 68-73°C. $^1\text{H-NMR}$ (DMSO- d_6): 2.35 ppm (tolylmethyl group).

Example A6: Preparation of compound 106



1.5 g of the compound 105 of Example A5, 1.63g of 12-bromododecanoic acid methyl ester and 844 mg of K_2CO_3 are dissolved in 25 ml of DMF and stirred for 9 hours at 65°C. The reaction mixture is poured in 2n of HCl and extracted with ethyl acetate. The organic phase is concentrated by evaporation and the crude product is then purified by chromatography over silica gel. Yield: 1.02 g pale yellow oil. $^1\text{H-NMR}$ (CDCl_3): 3.68 ppm (methyl ester).

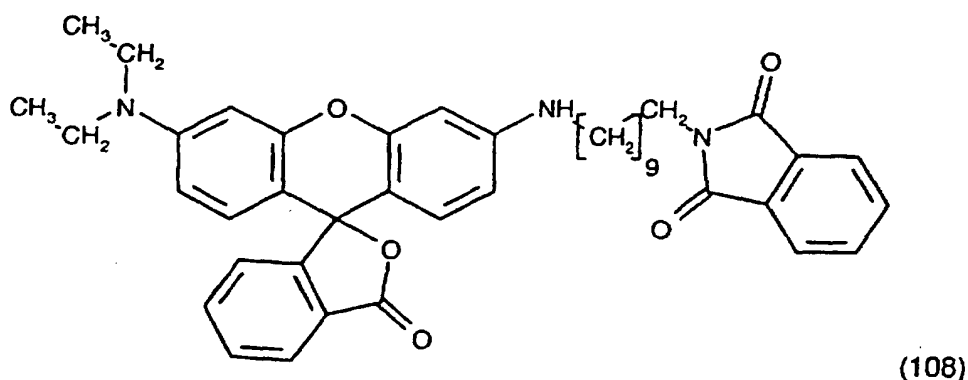
Example A7: Preparation of compound 107



2.5 g of the compound 105 of Example A5 are dissolved in 25 ml of DMF and then 1.4 g of potassium carbonate and 3.4 g of N-(10-bromodecyl)phthalimide are added. The mixture is heated to 70°C for 5 hours. The mixture is then poured in 300 ml of 1N HCl and extracted with methylene chloride. The organic phase is dried and concentrated by evaporation.

Purification is carried out by column chromatography over silica gel. Yield: 2.15 g (56%) yellowish crystals. MS (FD): 825.

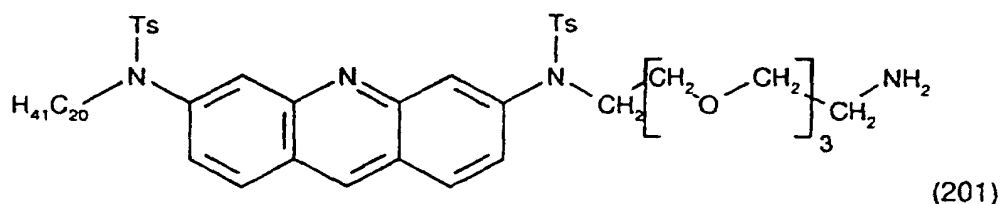
Example A8: Preparation of compound 108



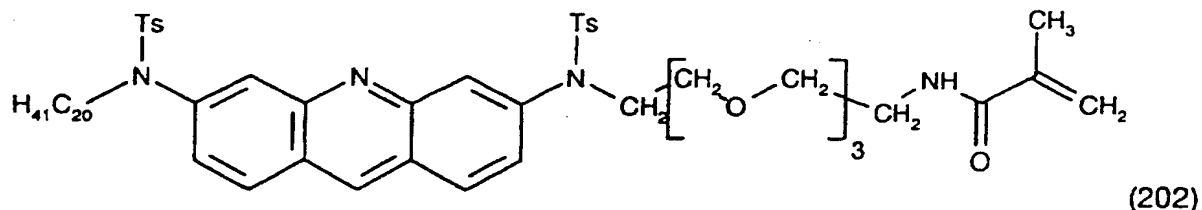
The compound 107 of Example A7 is stirred into a mixture of 5 parts of acetic acid and 2 parts of sulfuric acid (25 ml in all) for 18 hours at room temperature. The mixture is then poured in water and extracted with methylene chloride. The organic phase is washed with bicarbonate solution, dried and concentrated by evaporation. Yield: 1.61g pure product.

B) Preparation of the functionalised compounds

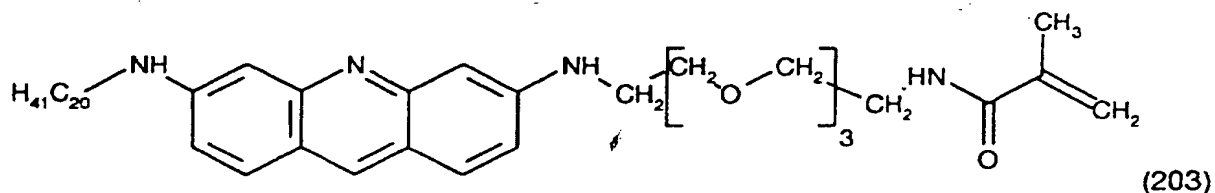
Example B1: Preparation of compound 201



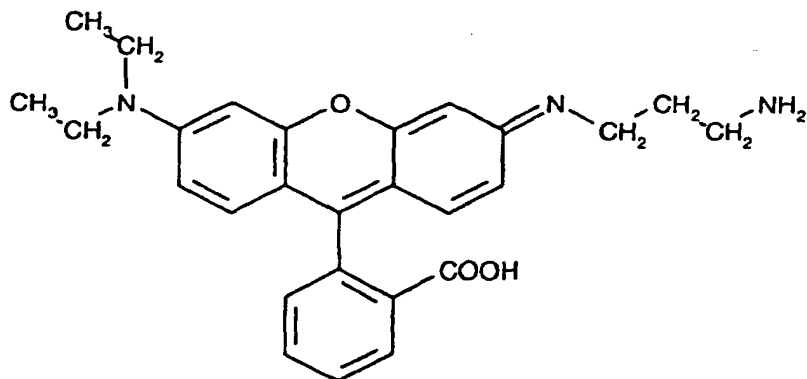
3.7 g of the compound 103 of Example 3 are stirred together with 1 ml of hydrazine hydrate in 20 ml of methylene chloride and 45 ml of methanol for 21 hours at room temperature. The resulting residue is isolated by filtration, washed thoroughly and the combined filtrates are concentrated by evaporation. The residue is purified by chromatography over silica gel. Yield: 41%. MS(FAB): 972.

Example B2: Preparation of compound 202

1.2 g of the compound 201 of Example B1 are added together with 190 mg of potassium carbonate to 70 ml of tetrahydrofuran and the mixture is cooled to 0°C. 132 mg of methacrylic acid chloride are dissolved in 20 ml of tetrahydrofuran and this solution is slowly added dropwise to the above suspension. After 1 hour at 0°C, the mixture is poured in 300 ml of 2N NaOH and extracted with ethyl acetate. The organic phase is dried and concentrated by evaporation. The residue is purified over silica gel. Yield: 82% yellow resin.

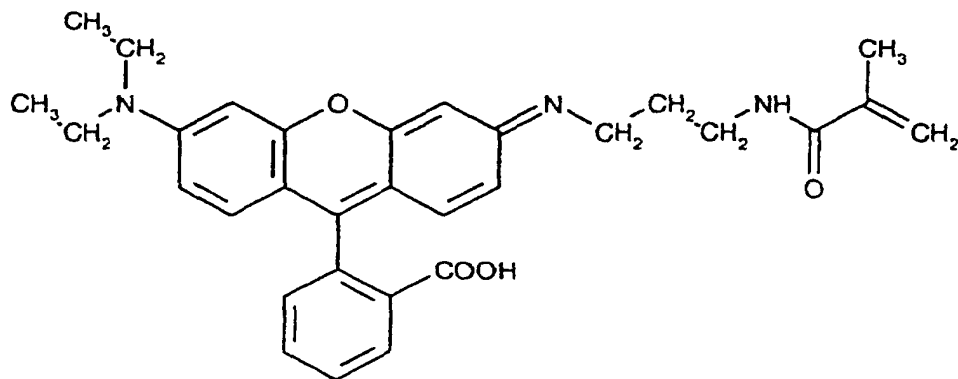
Example B3: Preparation of compound 203

980 mg of the compound 202 of Example B2 are stirred into a mixture of 5 parts of acetic acid and 2 parts of sulfuric acid (25 ml in all) over 18 hours at room temperature. The mixture is then poured in water and extracted with methylene chloride. The organic phase is washed with bicarbonate solution, dried and concentrated by evaporation. The residue is purified by chromatography over silica gel. Yield: 520 mg orange crystals. MS(FD):732. ¹H-NMR(CDCl₃): 1.95 (methacrylmethyl protons); 5.3 and 5.75 ppm (olefinic acryl protons).

Example B4: Preparation of compound 204

(204)

17.4 g (55.5 mmol) of 4-(2'-carboxy)benzoyl-3-hydroxy-N,N-diethylaniline are added in increments to 115 ml of sulfuric acid (95-97%) such that the temperature does not rise above 30°C. 3-Methoxy-N-(3-aminopropyl)aniline is then slowly added. The reaction mixture is stirred for 26 hours at room temperature and is then added, with vigorous stirring, to a mixture of toluene and aqueous NaOH. The organic phase is separated, dried and concentrated by evaporation. The aqueous phase is additionally extracted with methylene chloride and the organic phase is separated, dried and concentrated by evaporation.

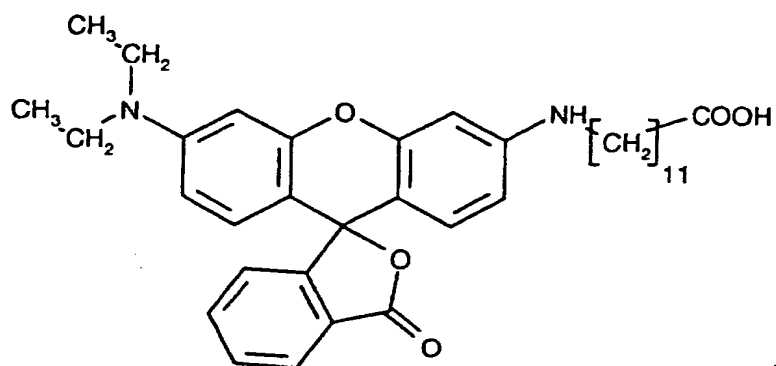
Example B5: Preparation of compound 205

(205)

500 mg of the compound 204 of Example B4 are dissolved in 40 ml of tetrahydrofuran. After cooling the red solution to 0°C, 187 mg of K₂CO₃ are added and then 117 mg of methacryloyl chloride in 10 ml of tetrahydrofuran are added dropwise. After 3 hours the mixture is poured in water and extracted with CH₂Cl₂. The separated organic phase is dried

and concentrated by evaporation. Purification by chromatography over silica gel gives 130 mg of red crystals. MS (m/z): 511. $^1\text{H-NMR}(\text{CDCl}_3)$: 5.0 and 5.55 ppm (olefinic acryl protons).

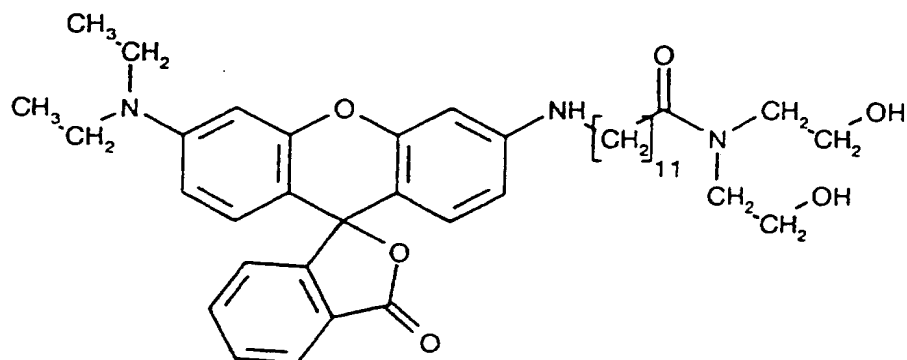
Example B6: Preparation of compound 206



(206)

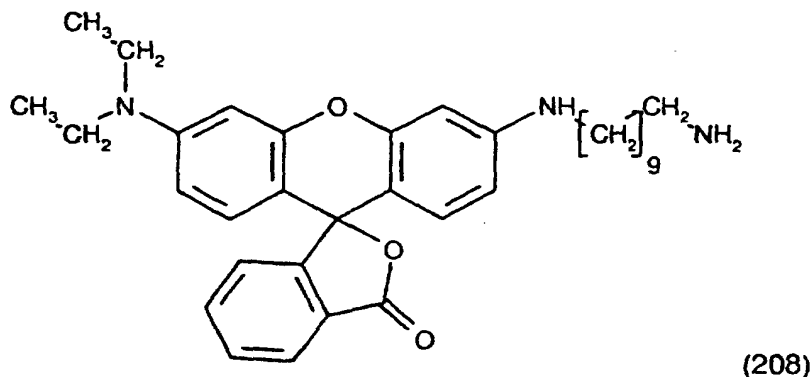
1 g of the compound 106 of Example A6 is stirred into a mixture of 5 parts of acetic acid and 2 parts of sulfuric acid (25 ml in all) for 5 hours at 65°C. The mixture is then poured in water and extracted with methylene chloride. The organic phase is dried and concentrated by evaporation. The residue is purified by chromatography over silica gel. MS (m/z): 584.

Example B7: Preparation of compound 207

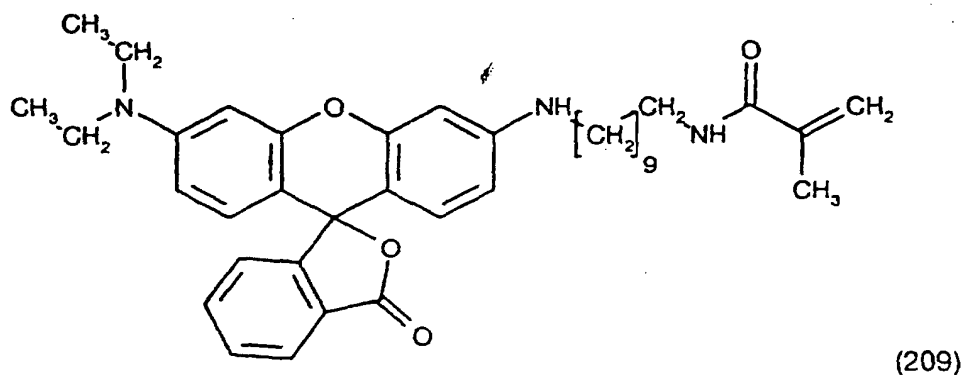


(207)

In in general accordance with the process described in *Helv. Chim. Acta* **1988**, 71, 2087, the compound 206 of Example B6 is activated at the free carboxylic acid functional group and then reacted with diethanolamine over 72 hours at room temperature. Yield: 73%. MS(FD): 671.

Example B8: Preparation of compound 208

1.6 g of the compound 108 of Example A8 are heated in 35 ml of 48% HBr over 21 hours to 110°C. After cooling, the reaction mixture is poured in 2N NaOH and extracted with methylene chloride. The organic phase is dried and concentrated by evaporation. Yield: 1.9 g of crude product which is used direct for the next step.

Example B9: Preparation of compound 209

1.9 g of the crude product of compound 208 of Example B8 are added to 50 ml of tetrahydrofuran and then 490 mg of potassium carbonate are added. To this mixture are slowly added dropwise 245 mg of methacryloyl chloride dissolved in 20 ml of tetrahydrofuran. After 2 hours the reaction mixture is poured into 400 ml of 1N NaOH and extracted with methylene chloride. The organic phases are washed with 1N HCl, dried and concentrated by evaporation. The crude product is purified by chromatography over silica gel. Yield: 40%. ¹H-NMR (DMSO-d₆): 1.90 ppm (methacrylmethyl), 5.35 and 5.68 (olefinic acryl protons).

C) Preparation of the polymer-bound fluorophores

Example C1: In a three-necked flask equipped with stirrer, 1. g of polytetrahydrofuran ($M_n = 2000$ g/mol), 0.69 g of hydroxypropyl-terminated polydimethylsiloxane (M_n 2740 g/mol), 0.09 g of butanediol and 0.005 mg of diazabicyclooctane are dissolved in 15 ml of anhydrous tetrahydrofuran under inert gas conditions (N_2 atmosphere). The reaction is allowed to proceed for 3 hours at 60°C with 0.40 g of methylene diphenyl diisocyanate.

In a second three-necked flask, also under inert gas conditions (N_2 atmosphere), 0.05 g of methylene diphenyl diisocyanate are dissolved in 2.5 ml of tetrahydrofuran and a solution of 0.022 g of fluorescent dye of formula 204 of Example B4 in 5 ml of tetrahydrofuran is then added dropwise at room temperature and the reaction is allowed to proceed for 1 hour. The resulting pink fluorescent solution is combined with the polymer solution mentioned above and the reaction is allowed to proceed for a further 3 hours at 60°C.

The polymer is precipitated by being poured in 500ml of methanol and is then isolated by filtration and dried under vacuum at 20°C. The product obtained is dissolved once more in 20 ml of tetrahydrofuran and precipitated in 500 ml of methanol, giving 1.85 g (81 % of theory) of pink polymer.

Example C2: In a three-necked flask equipped with stirrer, 1.0 g of polytetrahydrofuran ($M_n = 2000$ g/mol), 0.10 g of butanediol and 0.005 mg of diazabicyclooctane are dissolved in 15 ml of anhydrous tetrahydrofuran under inert gas conditions (N_2 atmosphere). The reaction is allowed to proceed for 3 hours at 60°C with 0.35 g of methylene diphenyl diisocyanate.

In a second three-necked flask, also under inert gas conditions (N_2 atmosphere), 0.05 g of methylene diphenyl diisocyanate are dissolved in 2.5 ml of tetrahydrofuran and then diluted dropwise with a solution of 0.019 g of fluorescent dye of formula 204 of Example B4 in 5 ml of tetrahydrofuran at room temperature, and the reaction is allowed to proceed for 1 hour. The resulting pink fluorescent solution is combined with the polymer solution mentioned above and the reaction is allowed to proceed for a further 3 hours at 60°C.

The polymer is then precipitated by being poured in 500ml of methanol and is then isolated by filtration and dried under vacuum at 20°C. The product is dissolved once more in 20 ml of tetrahydrofuran and precipitated in 500 ml of methanol, giving a pink polymer.

Example C3: 4.00 g of Tecoflex® polyurethane, supplied by Thermedics, together with 0.05mmol/g of OH terminal groups and 0.002 g of diazabicyclooctane are dissolved in a mixture of 30 ml of tetrahydrofuran and 25 ml of dimethylformamide and then a solution is added consisting of 0.055 g of methylene diphenyl diisocyanate and 0.067 g of the

compound of formula 207 of Example B7 in 5 ml of DMF. The mixture is allowed to react for 16 hours at 60°C. Further processing is carried out in general accordance with the procedure of Examples 1 and 2. The yield is 3.05 g (74 % of theory) of pink polymer.

Example C4: In a vial, equipped with a three-way tap connected to vacuum and nitrogen, 50 mg of the compound 209 of Example B9 are dissolved in 0.16 g (2.9 mmol) of acrylonitrile. To this solution are added 4.84 g (26.3 mmol) of 2-ethylhexylacrylate and 5 mg of azoisobutyronitrile (AIBN). The vial is closed and the atmosphere is exchanged three times by a freezing/thawing cycle with nitrogen. The vial is kept in a water bath at 60°C for 2 days. The viscous contents of the vial are then dissolved in 50 ml of toluene at 50°C and the polymer is precipitated in 1000ml of methanol. The pale red polymer is filtered, dried, dissolved again and then precipitated again under the same conditions. Drying is carried out over 24 hours under high vacuum. The yield is 1.9 g (38%) and the glass transition temperature is -58°C. The inherent viscosity of a 0.5 % solution in THF at 25°C is $\eta_{inh}=2.81$.

D) Use Examples, preparation and characterisation of the optical sensor

Example D1: Pretreated glass is used as carrier material. Round glass panes (diameter 18 mm, thickness 0.17 mm) are immersed for 1 hour into a solution of 10 vol % of dimethyldodecylchlorosilane in isopropanol. The glass panes are then washed in succession with 200 ml each of isopropanol, ethanol and methanol and dried for 1 h at 110°C. The adhesion of the membrane layer on the hydrophobised surface is improved.

The sensor membrane is prepared by dissolving 40 mg of the polymer described in Example C1, 1.5 mg of valinomycin and 1.2 mg of potassium tetrakis 3,5- bis(trifluoromethylphenyl)borate in 1.2 ml of tetrahydrofuran. The glass carriers are mounted in the chamber of a spin-coating apparatus (Optocoat OS 35var, Willer Company, CH-8484 Weisslingen). The chamber is rinsed with 10 ml of tetrahydrofuran and rotated for 2 min at 8000 rpm. Subsequently, 50 µl of the respective coating solution are pipetted on to the glass carrier which is then rotated for a further 10 sec. The membrane-coated glass carrier is taken out and dried for 10 min in the air.

The coated glass carriers are mounted in an optical cell wherein the membrane is in contact with the measuring liquid. In the optical cell the membrane can be optically excited and the fluorescence radiation can be measured. The optical cell is placed in a spectrofluorometer (Pekin-Elmer LS-50). The absorption and emission wavelengths are adjusted to the respective maxima of the fluorophores used in the membrane. The membrane is contacted

with an aqueous solution of KCl or CaCl₂ of defined concentration by pumping the solution at a rate of 1 ml/min through the cell and determining the change in fluorescence intensity. Rinsing with potassium ion-free buffer solutions is carried out before and after each measurement and the fluorescence intensity is measured in order to determine the base line. The fluorescence intensity (measured as change in voltage in the photodiode) at the respective potassium concentration for the fluorophore is listed below.

Potassium ion concentration in mmol	Fluorescence intensity in volt
0	6.8
0.5	4.8
4.0	4.3
10.0	4.1

Example D2: The procedure of Example D1 is repeated, the membrane for the sensor being composed of 20 mg of the polymer of Example C2, 1.5 mg of valinomycin and 1.2 mg of potassium tetrakis 3,5- bis(trifluoromethylphenyl)borate. The following values are obtained:

Potassium ion concentration in mmol	Fluorescence intensity in volt
0	6.3
0.5	4.9
4.0	4.7
10.0	4.6

Example D3: The procedure of Example D1 is repeated, the membrane for the sensor being composed of 40 mg of the polymer of Example C2, 3.0 mg of valinomycin and 2.0 mg of potassium tetrakis 3,5- bis(trifluoromethylphenyl)borate. The following values are obtained:

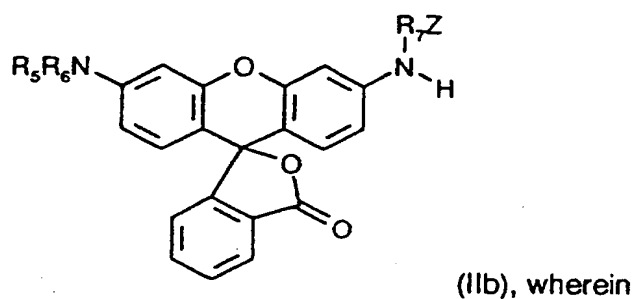
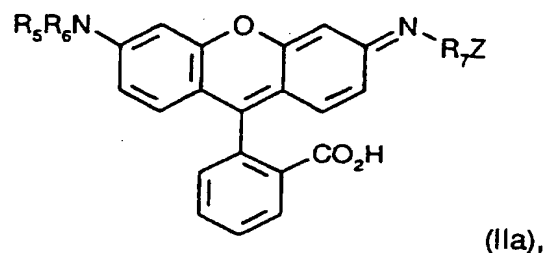
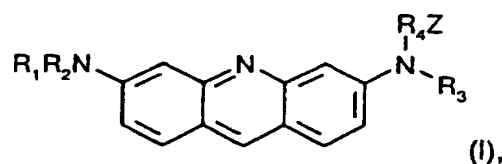
Potassium ion concentration in mmol	Fluorescence intensity in volt
0	2.9
0.5	1.7
4.0	1.6
10.0	1.5

Example D4: The procedure of Example D1 is repeated, the membrane for the sensor being composed of 75 mg of the polymer of Example C4, 1.5 mg of valinomycin and 1.2 mg of potassium tetrakis 3,5-bis(trifluoromethylphenyl)borate. The following values are obtained:

Potassium ion concentration in mmol	Fluorescence intensity in volt
0	2.8
0.5	1.6
4.0	1.2
10.0	1.0

What is claimed is

1. A compound of formula I, IIa or IIb



R_1 , R_2 , R_5 and R_6 are each independently of one another hydrogen, $-\text{SO}_2-(\text{C}_1-\text{C}_6)\text{alkylphenyl}$, $\text{C}_1-\text{C}_{30}\text{alkyl}$, $\text{C}_1-\text{C}_{30}\text{alkyl-CO-}$ or a radical of formula $-(\text{C}_n\text{H}_{2n}\text{-O})_m\text{-R}_{10}$;

R_3 is hydrogen or $-\text{SO}_2-(\text{C}_1-\text{C}_6)\text{alkylphenyl}$;

R_4 and R_7 are $\text{C}_1-\text{C}_{30}\text{alkylene}$ or a radical of formula $-(\text{C}_n\text{H}_{2n}\text{-O})_m\text{-R}_{10}$.

Z is a functional group which is selected from the group consisting of $-\text{OH}$, $-\text{SH}$, $-\text{NH}_2$, $-\text{COOH}$, $-\text{NCO}$, $-\text{CO-NR}_8\text{YR}_9\text{Y}$, $-\text{NH-CO-CH=CH}_2$, $-\text{NH-CO-C(CH}_3\text{)=CH}_2$;

R_8 and R_9 are each independently of the other $\text{C}_1-\text{C}_{30}\text{alkylene}$;

R_{10} is a direct bond or $\text{C}_1-\text{C}_{12}\text{alkylene}$;

n is a number from 2 to 6, and m is a number from 1 to 10, with the proviso that the total number of carbon atoms is at most 30;

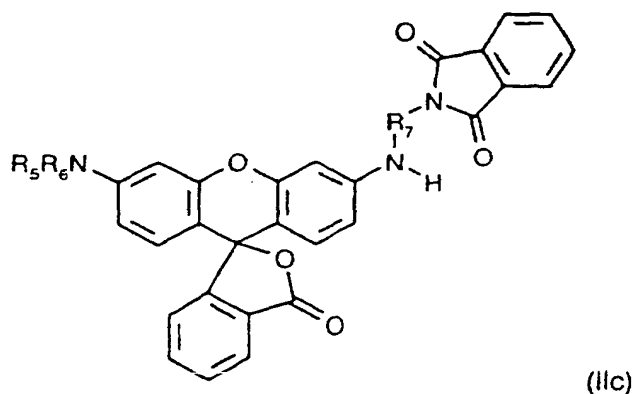
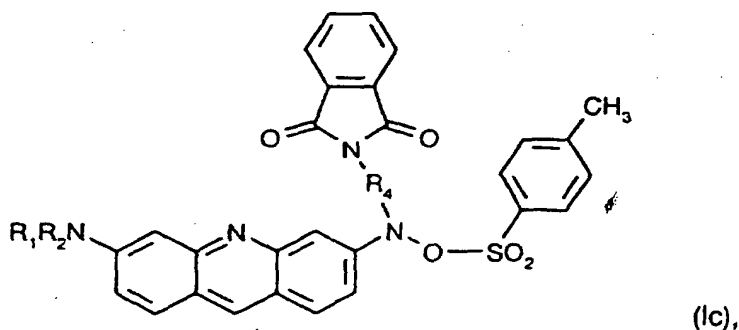
and Y is $-\text{OH}$ or $-\text{SH}$.

2. A compound of formula I according to claim 1, wherein R_1 and R_2 are each independently of the other hydrogen or linear $\text{C}_{12}-\text{C}_{24}\text{alkyl}$.

3. A compound of formula I according to claim 1, wherein R_4 is linear $\text{C}_2-\text{C}_{16}\text{alkylene}$ or a radical of formula $-(\text{C}_2\text{H}_4\text{-O})_m\text{-R}_{10}$, and R_{10} and m have the meanings defined in claim 1.

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4. A compound of formula IIa or IIb according to claim 1, wherein R_5 and R_6 are each independently of the other linear C_2 - C_{12} alkyl.
5. A compound of formula IIa or IIb according to claim 1, wherein R_7 is linear C_2 - C_{16} alkylene.
6. A compound of formula I, IIa or IIb according to claim 1, wherein the functional group Z is $-OH$, $-NH_2$, $-CO-NR_8YR_9Y$, $-NH-CO-C(CH_3)=CH_2$, and R_8 and R_9 are each independently of the other C_2 - C_8 alkylene.
7. A compound of formula IIa or IIb according to claim 6, wherein Y is OH.
8. A process for the preparation of the compounds of formulae I, IIa and IIb, which comprises
 - a) removing the phthalimide group in the compound of formula Ic or IIc



under acid conditions and, where appropriate,

- b) reacting the reaction products further with acrylic acid chloride or methacrylic acid chloride in a second step or,

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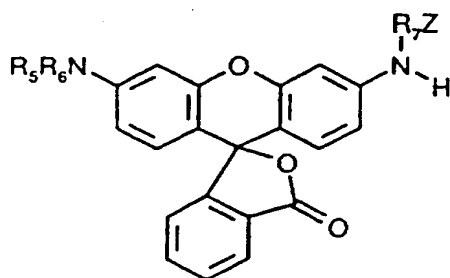
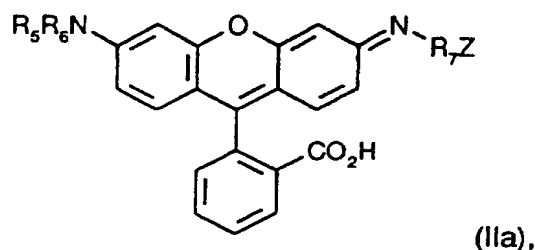
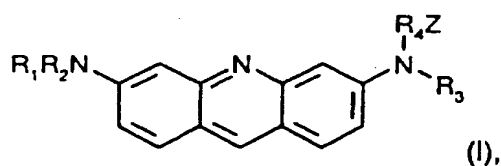
c) where appropriate, removing the p-toluenesulfonyl group in the reaction products of the educts of formula Ic under acid conditions,

R_1 , R_2 , R_4 , R_5 , R_6 and R_7 having the meanings cited above.

9. A plasticiser-free copolymer, which consists either

A) of at least one diol or at least one diamine or of mixtures of at least two of these monomers, and of at least one diisocyanate, or

B) of at least one olefinically unsaturated monomer, which copolymer additionally contains at least one comonomer of formula I, IIa or IIb



Z is -OH, -SH, -NH₂, -COOH, -NCO, or NR₈YR₉Y and Y is -OH or -SH and, in the case of B) Z is -NH-CO-CH=CH₂ or -NH-CO-CCH₃=CH₂, and R_1 , R_2 , R_3 , R_4 , R_5 , R_6 , R_7 , R_8 and R_9 have the meanings and preferred meanings cited above.

10. A copolymer according to claim 9, which is formed by at least one diol or one diamine and one diisocyanate.

11. A copolymer according to claim 9, wherein the amount of compounds of formula I, IIa or IIb is 0.01 to 10 % by weight, based on the amount of polymer.

12. A copolymer according to claim 9, wherein the amount of compounds of formula I, IIa or IIb is 0.1 to 5 % by weight, based on the amount of polymer.

13. A copolymer according to claim 9, which is polyurethane, polyurea or polyurea-polyurethane.

14. A copolymer according to claim 9, wherein the polyurethane consists of polyethers of C₃-C₆alkanediols, polyoxyalkylenediols or hydroxy-terminated siloxanes and aliphatic, cycloaliphatic, cycloaliphatic-aliphatic, aromatic-aliphatic or aromatic C₂-C₂₀diisocyanates.

15. A copolymer according to claim 9, wherein the diisocyanate is selected from the group consisting of 1,6-bis[isocyanate]hexane, 5-isocyanate-3-(isocyanatemethyl)-1,1,3-trimethylcyclohexane, 2,4-bis[isocyanate]toluene, 2,6-bis[isocyanate]toluene, 2,4-/2,6-bis[isocyanate]toluene, bis[4-isocyanatecyclohexyl]methane or bis[4-isocyanatephenyl]-methane.

16. A copolymer according to claim 9, wherein the polyurethane is obtained by reacting

a) 5-45 % by weight of an aromatic, cycloaliphatic or linear aliphatic diisocyanate,

b) 0-20 % by weight of a linear or branched C₂-C₁₂alkylenediol

c) 0-75 % by weight of a polytetrahydrofuran

d) 0-10 % by weight of a polyethylene glycol

e) 0-75 % by weight of a polypropylene glycol and

f) 15-95 % by weight of a hydroxy-terminated or hydroxypropyl-terminated polydimethylsiloxane

g) 0.1-5 % by weight of a fluorophore of formula I, IIa or IIb,

where the percentages are based on the amount of polymer and the parts by weight of the components a) to g) give a sum of 100.

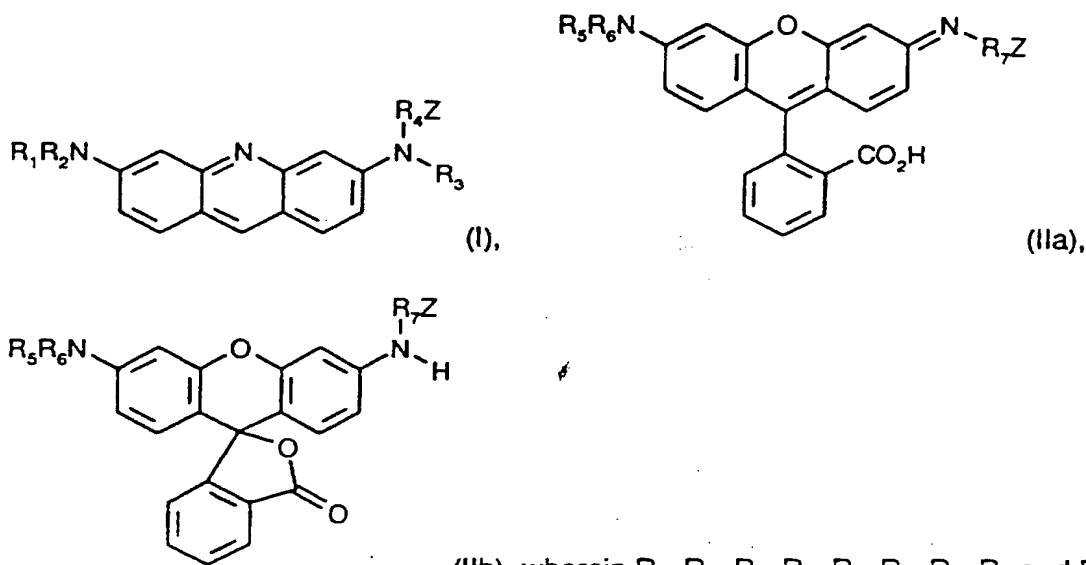
17. A copolymer according to claim 9, wherein the fluorophores in the polymer are essentially terminally distributed.

18. A copolymer according to claim 16, wherein the hydroxy-terminated, or hydroxypropyl-terminated polydimethylsiloxane has a molecular weight of 900 to 4500 dalton.

19. A copolymer according to claim 16, wherein the polytetrahydrofuran has a molecular weight of 1000 to 4500 dalton.

20. A copolymer according to claim 16, wherein the polyethylene glycol has a molecular weight of 600 to 2000 dalton and the polypropylene glycol has a molecular weight of 1000 bis 4000 dalton.

21. A copolymer according to claim 16, wherein the monomers are selected from the compounds of the group consisting of acrylic acid, methacrylic acid, maleic acid, maleic acid anhydride, C₁-C₃₀acrylic acid ester and C₁-C₃₀methacrylic acid ester, C₁-C₃₀acrylic acid amide and C₁-C₃₀methacrylic acid amide or acrylic acid amide and methacrylic acid amide, vinyl ester of C₁-C₂₀carboxylic acids, acrylonitrile, butadiene, isoprene, styrene, α -methylstyrene, and vinyl ether of C₁-C₃₀alcohols and a compound of formula I, IIa or IIb



wherein $R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8$ and R_9 have the meanings claimed in claim 1 and Z is $-NH-CO-CH=CH_2$ or $-NH-CO-C(CH_3)=CH_2$.

22. A copolymer according to claim 21, which comprises the compounds of formula I, IIa or IIb in an amount of 0.01 to 10 % by weight, based on the entire polymer.

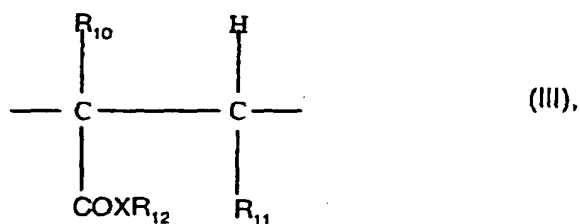
23. A copolymer according to claim 21, which comprises the compounds of formula I, IIa or IIb in an amount of 0.1 to 5 % by weight, based on the entire polymer.

24. A copolymer according to claim 21, which comprises the compounds of formula I, IIa or IIb in an amount of 0.1 to 2 % by weight, based on the entire polymer.

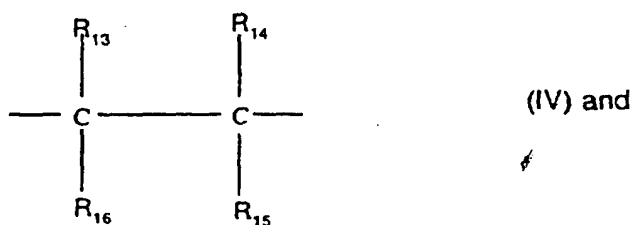
25. A copolymer according to claim 21, comprising

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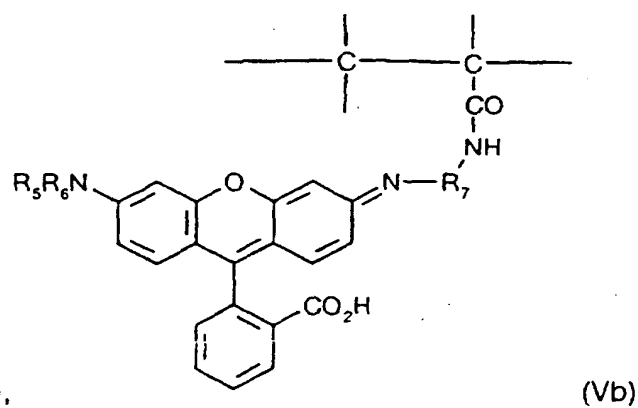
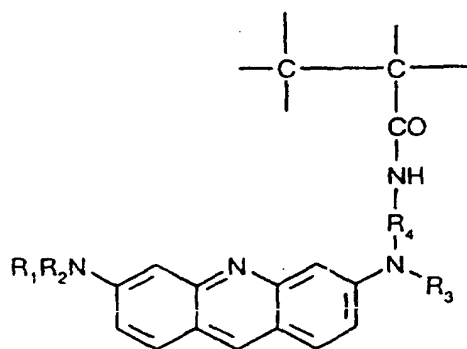
a) 10 to 90 % by weight, preferably 20 to 80 % by weight and, particularly preferably, 30 to 70 % by weight, based on the polymer, of identical or different structural elements of formula III



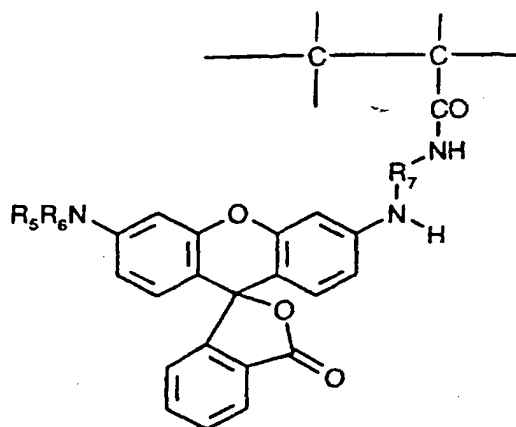
b) 90 to 10 % by weight, preferably 80 to 20 % by weight and, particularly preferably, 70 to 30 % by weight, based on the polymer, of identical or different structural elements of formula IV



c) 0.1 to 5 % by weight of at least one structural element of formula Va, Vb or Vc



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(Vc), wherein R_1 , R_2 , R_3 , R_4 , R_5 , R_6 , R_7 , R_8 and R_9 have the meanings claimed in claim 1; R_{10} and R_{11} are each independently of the other H or C_1 - C_4 alkyl, X is -O- or - NR_{17} , R_{12} is C_1 - C_{20} alkyl; and R_{17} is H or C_1 - C_{20} alkyl; R_{13} and R_{14} are each independently of the other H, F, Cl or C_1 - C_4 alkyl, R_{15} and R_{16} are each independently of the other H, F, Cl, C_1 - C_4 alkyl, -COOH, -COO- C_1 - C_5 alkyl, -CONHC $_1$ - C_5 alkyl or -CON(R_{17}) C_1 - C_5 alkyl, or R_{15} is H and R_{16} is -CN, phenyl, chlorophenyl, C_1 - C_{12} alkoxy or C_2 - C_{18} acyloxy.26. A copolymer according to claim 25, wherein R_{10} is H or methyl, R_{11} is H, and X is -O-.27. A copolymer according to claim 25, wherein R_{12} is C_1 - C_{16} alkyl, R_{13} is H or methyl, R_{14} and R_{15} are H, and R_{16} is -CN, phenyl, -COO- C_1 - C_4 alkyl, C_1 - C_4 alkoxy or C_2 - C_6 acyloxy.

28. A copolymer according to claim 9, which has a glass transition temperature of -150°C to 50°C.

29. A copolymer according to claim 28, which has a glass transition temperature of -125°C to -40°C.

30. A copolymer according to claim 9, which has a molecular weight of 10 000 to 250 000 dalton.

31. A copolymer according to claim 25, which has a molecular weight of 10 000 to 100 000 dalton.

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32. An optical sensor consisting of

- (a) a transparent carrier which is coated on at least one side with a transparent layer of a polymer as claimed in claim 8,
- (b) counterions in the form of lipophilic salts, and
- (c) a ionophore which forms a complex with the ion to be determined.

33. An optical sensor according to claim 32, wherein the carrier is a glass.

34. An optical sensor according to claim 32, wherein the thickness of the layer on the carrier is from 0.1 to 100 μm .

35. An optical sensor according to claim 32, wherein the salts containing lipophilic anions are alkali metal salts, alkaline earth metal salts and ammonium salts with unsubstituted or substituted tetraphenylborates.

36. An optical sensor according to claim 32, wherein the cations are Li^+ , Na^+ , K^+ , Mg^{2+} , Ca^{2+} , NH_4^+ , and the ammonium cations are those of primary, secondary and tertiary amines as well as quaternary ammonium cations containing 1 to 40 carbon atoms.

37. An optical sensor according to claim 32, wherein the borate anion is tetraphenylborate, the phenyl groups of which are unsubstituted or substituted by one or more than one C_1 - C_4 alkyl, C_1 - C_4 alkoxy, halogen or trifluoromethyl.

38. An optical sensor according to claim 32, wherein the borate anion is tetraphenylborate, tetra(3,5-bistrifluoromethylphenyl)borate or tetra(4-chlorophenyl)borate.

39. An optical sensor according to claim 32, wherein the amount of salts with lipophilic anions is from 0.01 to 10 % by weight, based on the amount of polymer.

40. An optical sensor according to claim 32, wherein the polymer layer comprises a ionophore in an amount of 0.1 to 5 % by weight, based on the amount of polymer.

41. An optical sensor according to claim 32, wherein the potassium ionophore is valinomycin.

42. A process for the optical determination of ions in aqueous test samples, which comprises contacting a sensor as claimed in claim 32 with said aqueous test sample and then measuring the change in fluorescence of the fluorophore in the polymer layer.

43. Use of the optical sensor as claimed in claim 32 for the optical determination of cations or anions.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 96/03954

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C07D311/82 C07D219/08 C07D493/10 G01N31/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C07D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 623 599 (CIBA-GEIGY) 9 November 1994 see the whole document	1,2,8,9, 21,32
A	EP,A,0 561 738 (CIBA-GEIGY) 22 September 1993 see claims; table 1	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search

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Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Francois, J

INTERNATIONAL SEARCH REPORT

Information on patent family members

Internat. Application No

PCT/EP 96/03954

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-623599	09-11-94	CA-A- 2119840 JP-A- 6321908	27-09-94 22-11-94

EP-A-561738	22-09-93	BR-A- 9301195 JP-B- 2533731 JP-A- 6008620 US-A- 5395948	21-09-93 11-09-96 18-01-94 07-03-95
